# Near Field Probe Correction using Least Squares Filtering Algorithm

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*Abstract*—**The deconvolution technique is widely used for probe correction in the near field technique measurement. However, the measurement noise makes the result obtained by this method inefficient and requires the use of a very low noise measurement facility. In this paper, we present a method to improve the probe correction accuracy by an inverse filtering approach that takes into account the statistical characteristics of the measurement noise using the constrained least squares filtering algorithm (CLSF). Computations with EM software data of two different structures illustrate the reliability of the method.**

## I. Introduction

Nowadays, technological progress allows developing integrated circuits with higher speed and smaller size. These developments have increased the electromagnetic interferences (EMI) which are difficult to diagnose with conventional measurement systems. The measurement of the near-field emitted from electronic devices appears to be a promising approach in electromagnetic compatibility studies. Consequently, different mapping techniques have been developed to investigate the electromagnetic field in the immediate vicinity of the circuit under test to appreciate the electromagnetic interactions and find the appropriate solutions.

However, the measured field is directly correlated with the used probe and a post-processing step is needed to extract the actual device under test radiated field. This is called probe compensation techniques. One of these methods is the complex deconvolution technique.

The complex deconvolution technique has been used in near-field probe correction in [1-3] in order to enhance the measurement data resolution. Also, a high resolution characterization of the device under test emitted field requires the use of a small probe [4]. Hence, a small probe possesses a lower sensitivity, and consequently, a reduced signal to noise ratio. However, as presented in [1] and [2], authors have neglected the measurement noise contribution. This drawback makes the result obtained by the deconvolution method inefficient and requires the use of a very low noise measurement facility.

In this paper we propose an improved deconvolution technique based on the inverse filtering approach that takes into account the apriori information concerning the statistical characteristics of measurement noise.

Using the constrained least squares filtering (CLSF) process [5], which has been applied successfully in digital image processing, we can guarantee the stability of the deconvolution technique when data are corrupted by noise. The CLSF process quires the knowledge of the mean and the variance of the measurement noise. These parameters can be calculated easily from the measured signal.

## II. Method

The measured signal collected by the probe $v(x,y,h,f)$ at the given height $h$ and the frequency $f$, is the result of the convolution of the exact field distribution $e(x,y,h,f)$ and the probe response (transfer function) $h(x,y,h,f)$. The measured signal is possibly corrupted by the noise function $n(x,y,h,f)$ introduced during the measurement.

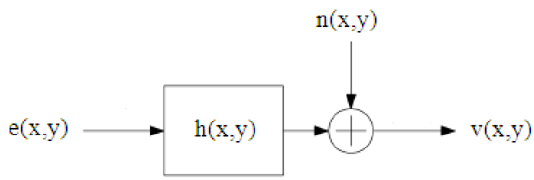


**Figure 1. Test procedure**

The test procedure is written as:

$$v(x,y,h,f) = e(x,y,h,f) * h(x,y,h,f) + n(x,y,h,f)$$

$$v(x,y,h,f) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} e(x,y,h,f)h(x-x',y-y',h,f)dx'dy' + n(x,y,h,f) \quad (1)$$

$$where \;\; e \in \{e_x, e_y, e_z, h_x, h_y, h_z\}$$

$e_x$, $e_y$, $e_z$, $h_x$, $h_y$, $h_z$ represent electric and magnetic field components.

The convolution integral is easily evaluated in a spectral domain as a simple multiplication of two dimensional Fourier transform of the respective functions.

$$V(kx,ky,kz,f) = E(kx,ky,kz,f).H(kx,ky,kz,f) + N(kx,ky,kz,f)\,. \quad (2)$$

Capital letters indicate the 2-D Fourier transforms of the corresponding spatial functions.

Many studies on this issue in [1-3] have evaluated the device under test radiated field using direct inverse filtering (DIF) technique. The estimated field *E'(kx,ky,kz,f)* is calculated by dividing the Fourier transform of the measured signal *V(kx,ky,kz,f)* by the Fourier transform of the probe response *H(kx,ky,kz,f)*. Nevertheless, the DIF technique has been applied without taking into account the measurement noise.

Determining the field E*(kx,ky,kz,f)* from the expression (2) shows that

$$\begin{aligned} E'(kx,ky,kz,f) &= \frac{V(kx,ky,kz,f)}{H(kx,ky,kz,f)} + \frac{N(kx,ky,kz,f)}{H(kx,ky,kz,f)} \\ E'(kx,ky,kz,f) &= E(kx,ky,kz,f) + \frac{N(kx,ky,kz,f)}{H(kx,ky,kz,f)} \end{aligned} . \quad (3)$$

Equation 3 illustrates that even if the probe response is well known, we cannot accurately determine the exact DUT radiated field *E(kx,ky,h,f)*. Indeed, the impact of measurement noise can become important for the case where *H(kx,ky,h,f)* takes very small values.

In this work we propose to solve this problem by an inverse filtering approach that integrates the statistical characteristics of noise using the constrained least squares filtering (CLSF) [5]. This method requires the knowledge of the mean and the variance of the noise. This is an important advantage over other types of inverse filtering that require the knowledge of the power spectral density of noise (Wiener filter) [5] in the sense that these parameters (mean and variance) can be evaluated easily for each measurement setup.

The objective of the probe compensation technique based on the constrained least squares filtering is to obtain an estimated field *e'(x,y,h,f)* of the exact field *e(x,y,h,f)* which minimizes the criterion function *C* defined by Eq. 4,

$$C = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left|\nabla^2 e(x,y)\right|^2 . \quad (4)$$

Subject to the constraint

$$\left\| v - h * e' \right\|^2 = \left\| n \right\|^2 , \quad (5)$$

where $\| \;\|$ is the $L^2$ norm. $\nabla^2$ is the Laplacian operator; M and N are the dimensions of the matrix *e (x, y).*

The solution for this optimization problem in the spectral domain is given by Eq. 6

$$E'(kx,ky) = \left[\frac{H^*(kx,ky)}{\left|H(kx,ky)\right|^2 + \beta\left|P(kx,ky)\right|^2}\right] V(kx,ky) . \quad (6)$$

Where, H*(kx,ky) is the complex conjugate of H(kx,ky).

β is a parameter to be adjusted, that, in practice, can be estimated by

$$\beta = \sigma_n^2 / (\sigma_v^2 - \sigma_n^2) . \quad (7)$$

where $\sigma_n^2$ is the measurement noise n(x,y) variance and $\sigma_v^2$ is the measured signal v(x,y) variance.

P(kx,ky) is the Fourier transform of the discrete 2D Laplacian operator determined by:

$$p(x,y) = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} . \quad (8)$$

## III. PROBE RESPONSE

To test the efficiency of this method, we choose a probe measuring the normal electric field such a semi-rigid coaxial cable. The response of this kind of probe is modeled by a mathematical function as a Ricker wavelet weighted by a factor *a* [3][6]. The Ricker wavelet function is expressed in (9) and presented in Fig 2.

$$h(x,y) = \left(1 - 2\pi^2 a^2 (x^2 + y^2)\right)\exp\left(-\pi^2 a^2 (x^2 + y^2)\right) . \quad (9)$$

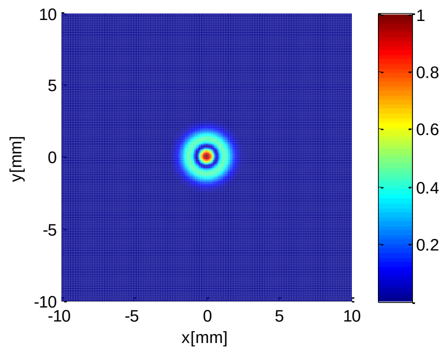


**Figure 2. The 2D normalized probe response for a frequency of 1GHz.**

This study is performed for two different devices under test (DUT) at the frequency of 1 GHz. The first DUT is a patch antenna where the rate of change in normal electric field is smooth due to the fact that the electric charges are distributed over a large circular area. The second structure is a quadrature hybrid coupler. This device radiates a very concentrated normal electric field above relatively narrow strips.

The two DUT (patch antenna and coupler) are etched on a standard epoxy FR4 laminate in a microstrip technique. The geometric characteristics of both structures are detailed in Fig.3.

The structures are simulated using CST Microwave Studio [7]. Then, the computed normal component of the electric field, *ez(x,y)*, is determined within a rectangular plane of size 100 x 100 $mm^2$. The measurement plane is located at 1 mm above their upper surface. The *ez(x,y)* field is sampled every 0.5 mm in both directions *x* and *y*. The field magnitude at the edges of the scanning plane should be zeros to prevent the truncation error in an inverse discrete Fourier calculation. The results of these simulations are used as a reference for evaluating the efficiency of the presented post-processing methods. In fact, the noise level of the reconstructed field is determined by comparing the actual field *e(x,y)* with the reconstructed one *e'(x,y)*.

## IV. RESULTS

The noiseless voltage *v(x,y)* is calculated by a convolution product between the mathematical functions representing the probe response and the normal electric field radiated by the corresponding DUT issued from the simulation.

Thereafter, a controlled noise *n(x,y)* is added to the calculated voltage *v(x,y)* with a given variance value. The goal of this part of the study is to estimate the normal field (*ez'(x,y)*) from a noisy voltage signal.

As it can be seen from Table 1, using a DIF technique, a small perturbation on the voltage signal *v(x,y)* generates a large disturbance on the reconstructed field, in such a way, that we totally loose the field characteristics for an added noise level of-60 dB (Fig.4 (c)).

Also, using the CLSF technique, the effect of the added noise has been controlled for both DUTs. As presented in Fig.4 and Fig.5, for an added noise level of -60dB, the reconstructed field has an average 2D error less than -37dB. Visually, it is a very satisfactory reconstructed field compared with the DIF technique results.

In Table.1, we present the β value corresponding to each added noise level. In order to verify the stability of *e'(x,y)* reconstruction as a function of β variation, we have considered the case for which the added noise level is -60dB.

From Table.1, an added noise level of -60 db corresponds to β =0.0052 (this value is given by the Eq.7). For -20% of the β initial value the CLSF technique leads to +2.5% variation of the reconstructed field noise level.
For +20% of the initial β value the CLSF technique leads to -4.5% variation of the reconstructed field noise level.

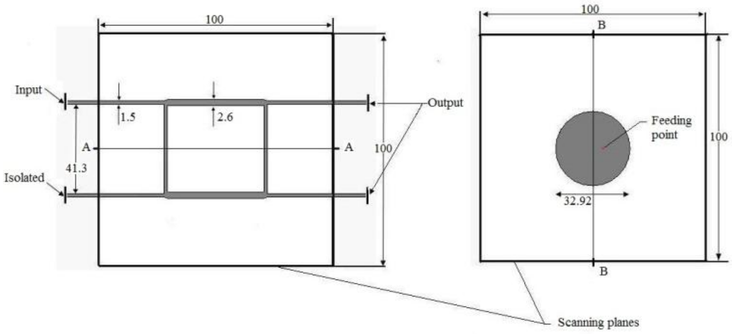


**Figure 3. Upper view and description of the used devices under test. (left) quadrature hybride coupler, (right) circular patch antenna**.

**TABLE I. RECONSTRUCTED FIELD NOISE LEVELS *ISSUED FOM DIF AND CLSF TEHNIQUES* FOR A MEASUREMENT DISTANCE OF 1MM AND A FREQUENCY OF 1GHZ**

| | | **Patch antenna** | | **quadrature hybrid coupler** | |
|---|---|---|---|---|---|
| ***v(x,y)* added noise level (dB)** | **Value of β** | **Noise level (dB) of *e'(x,y)* using DIF** | **Noise level (dB) of *e'(x,y)* using CLSF** | **Noise level (dB) of *e'(x,y)* using DIF** | **Noise level (dB) of *e'(x,y) using* CLSF** |
| -100 | $5.2\ 10^{-5}$ | -48 | -62 | -51 | -63 |
| -80 | $5.18\ 10^{-4}$ | -28 | -50 | -31 | -50 |
| -60 | 0.0052 | -11 | -36 | -13 | -37 |
| -40 | 0.051 | -10 | -26 | -10 | -24 |

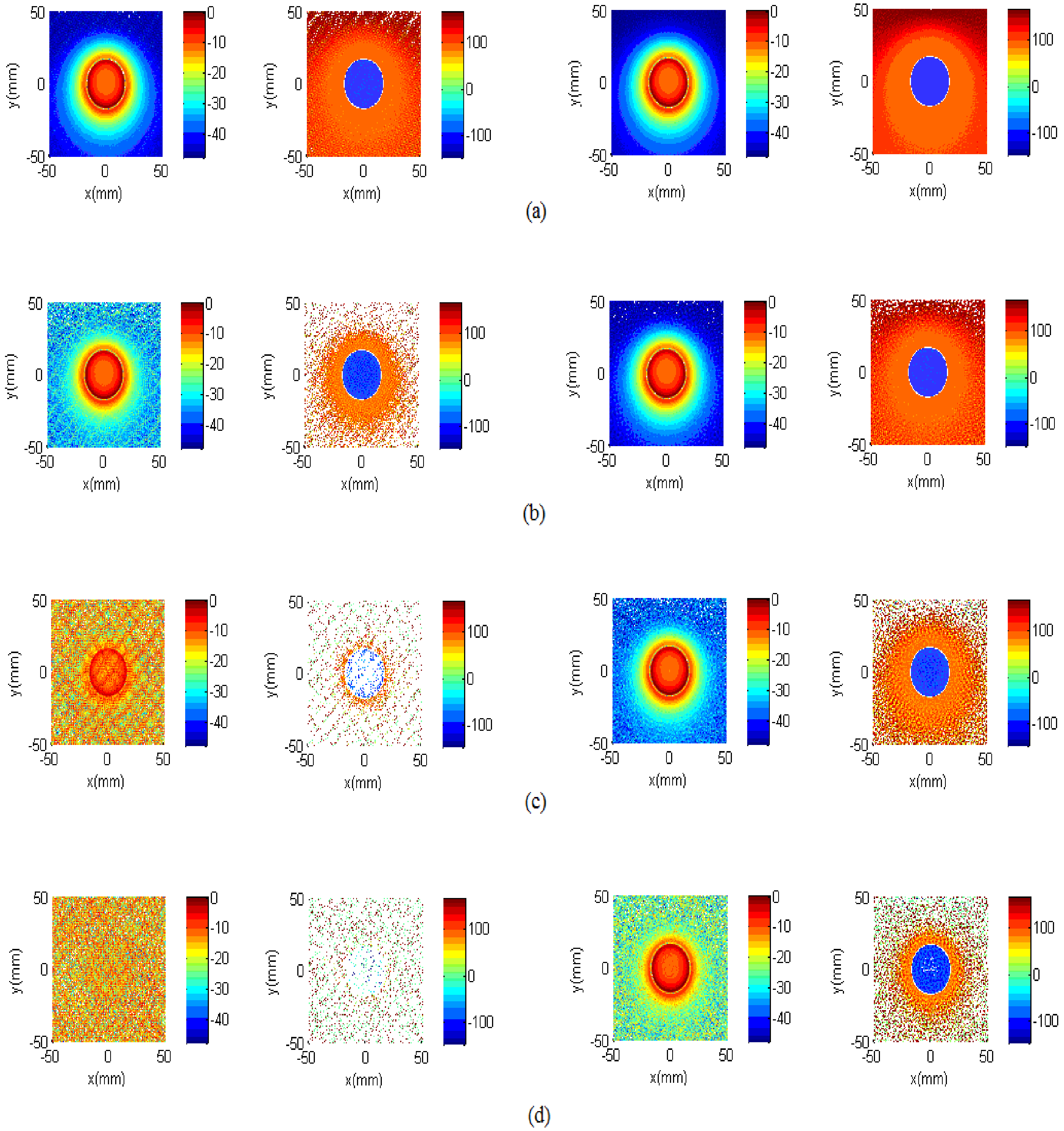


**Figure 4.** **The normalized amplitude [dBV/m] and phase [deg] of the normal electric field radiated by the patch antenna calculated by DIF (left) and CLSF (right), for different added noise levels, a:-100dB, b:-80dB, c:-60dB and d:-40 dB**

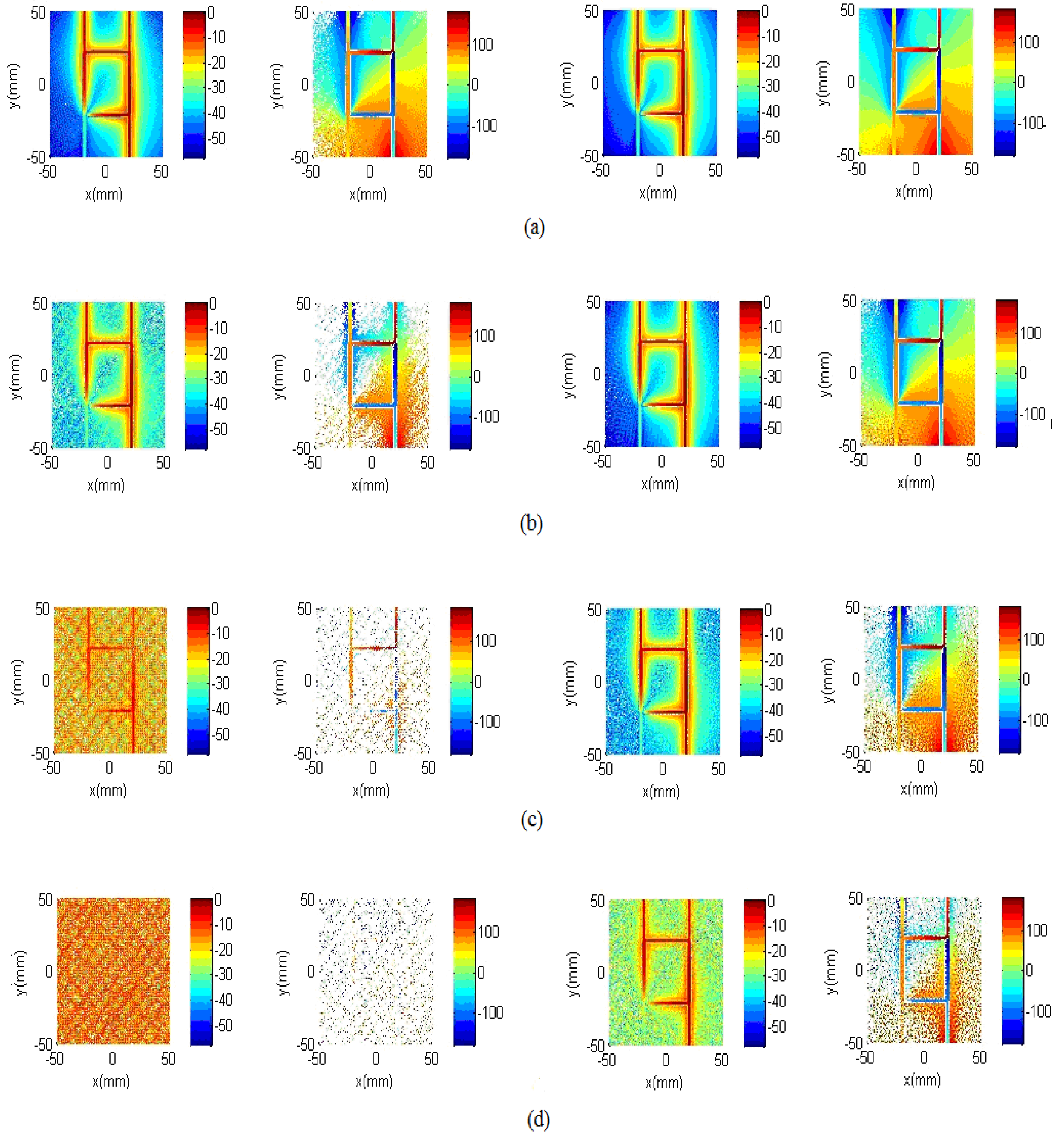


**Figure 5.** The normalized amplitude [dBV/m] and phase[deg] of the normal electric field radiated by the quadrature hybrid coupler calculated by DIF (left) and CLSF (right), for different noise levels, a:-100 dB, b:-80 dB, c:-60 dB and d:-40dB

## V. Conclusion

In this work we have shown that the classical deconvolution technique for probe correction based on direct Inverse Filtering (DIF) can present some limitations caused by the presence of the measurement noise. Consequently, a filtering technique has been proposed to overcome this limitation. Based on constrained least squares filtering, the correction method proposed in this work has shown a good ability to reduce strongly the effect of noise and have given very satisfactory results even for high level of noise. In addition, this method requires only the noise statistical characteristics, which are easily obtained from the measurement setup.

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